(54) Title: INPUT AND OUTPUT MONITORED AMPLIFIER

(57) Abstract

A system and method are disclosed for monitoring input signal power for an optical amplifier without disturbing the input signal. In one embodiment, a small part of the output signal (114) is split off and then bandpass filtered to provide a bandpass signal with energy that is attributable only to amplified spontaneous radiation (ASE) generated within the optical amplifier. The power in the bandpass signal is measured by an optical detector (314). Then, using the measured bandpass signal power and a one-to-one correlation between bandpass signal power and input signal power, a controller (316) estimates the input signal power value that corresponds to the measured bandpass signal power.

![Diagram of the system and method for monitoring input signal power for an optical amplifier.](image-url)
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INPUT AND OUTPUT MONITORED AMPLIFIER

The present invention relates generally to optical amplifiers and, particularly, to methods of monitoring the signal power at the input of an optical amplifier likely to be used in a fiber-optic information transmission system.

BACKGROUND OF THE INVENTION

A large number of applications utilize solid state lasers and amplifiers to generate or amplify light at specific wavelengths. Examples of such applications include the medical treatment of glaucoma by laser, surgery utilizing laser cutting and cauterizing of tissue, industrial metal treatment and welding using lasers and the amplification of light in a fiber communication system.

Solid state lasers generally contain a lasing element such as a rare earth or other atomic constituent in a glass or crystal matrix. The matrix can be in the form of a plate, a rod or an optical fiber. The fiber form is advantageous because it maintains the concentration of the light energy in a small area of the matrix and thus increases the power density. Traditionally solid state lasers require a light source at a preferred wavelength to excite the lasing element in the glass or crystal. Discharge lamps and flash lamps have been used in the past to pump such solid state lasers. More recently semiconductor lasers whose wavelength matches more closely the absorption band of the lasing element have been used to excite or pump the lasing
elements. For example, Indium Gallium Arsenide lasers emitting at a wavelength of 780 nm are used to pump Neodymium YAG (yttrium aluminum garnet) solid state lasers.

Another type of solid state device using semiconductor pump lasers is the doped fiber laser or light amplifier 100 shown in Figure 1. Light amplifiers of this type are well-known and consist of at least one pump laser 102, a wavelength-division multiplexer ("WDM") 104, and a section of active fiber 106 whose core area is doped with rare earth ions. The WDM 104 multiplexes the pump laser signal 108 and the light signal to be amplified 110 and outputs the multiplexed signal 112 to the active fiber 106. Using the power in the multiplexed signal 112 contributed by the pump laser 102, the active fiber 106 outputs an amplified version 114 of the light signal 110.

In many applications, especially in systems that include multiple, cascaded optical amplifiers, it is necessary to monitor the input power of an optical amplifier (hereinafter referred to as an "OA") in order to determine the occurrence of transmission faults preventing signal propagation at the OA's output. Such transmission faults might be caused by the failure of a pump laser 102 or a WDM 104. Prior art systems accomplish input power monitoring by introducing an outcoupler at the input of an OA that splits off a small amount of the power in the input signal. The split off signal is then analyzed by a detector that determines whether the input signal level is high or low. Transmission faults are then diagnosed by comparing the power in the input signal to the power in the OA's output signal.

One problem with this method of monitoring the signal at an OA's input is that it reduces the OA's input power and it is well known that the signal-to-noise ratio at the output of an OA is directly related to the power in the input signal. Thus, input power monitoring achieved by splitting-off a portion of the input signal power of an OA increases noise at the OA's output. In applications where multiple OAs are cascaded, such input monitoring techniques could increase the noise level at each stage until the output signal is seriously degraded and, perhaps, undetectable.
Another prior art system for monitoring the power of an OA's input signal is described in a U.S. Patent entitled "Fiber-Optic Amplifier with a Facility for Monitoring the Pump Power and Input Power" (U.S. Patent Number 5,422,479, granted on August 15, 1995 to Bülow et al.). In this system, a four-port optical coupler is provided at the input of the OA. An optical-to-electrical transducer is configured at one of the coupler's outputs to measure the strength of backward-propagating radiation (i.e., light propagating in a direction opposite that of the signal). This backward-propagating radiation results from ASE (amplified spontaneous radiation) occurring in the OA, meaning that the strength of the detected radiation provides information related to the strength of the input signal.

This method of monitoring input signal power suffers from the same problems (signal degradation and increased signal noise) as the other prior art systems. This is because Bülow et al.'s optical coupler is configured between the input signal and the optical amplifier, where it causes significant power losses in the input signal before amplification by the OA. These losses are in part due to splices required to connect the coupler's input ports to the fiber carrying the input signal and the OA's input, and to outcoupling by the coupler of a portion of the input optical energy to the coupler's output ports. These losses could easily total 10% of the input signal power, resulting in a 1dB increase in the output signal noise level and a significant degradation in signal quality.

Thus, there is a need for a system and method for monitoring the input signal of an OA that minimizes the power loss at the OA's input and the level of noise at the OA's output. There is also a need for a system and method that, cooperatively with the needed low noise input monitoring technique, monitors the output signal of an OA and compares the output and input signals to determine the presence of transmission faults in the OA.
SUMMARY OF THE INVENTION

In summary, the present invention is an improved system and method for monitoring the input signal of an OA that minimizes the power loss at the OA's input and the level of noise at the OA's output. The present invention also is a system and method that, cooperatively with the improved input monitoring technique, monitors the output signal of an OA and compares the output and input signals to determine the presence of transmission faults in the OA.

In particular, the present invention is a system for input power monitoring for use in an optical amplifier that includes at least one pump laser, a wavelength-division multiplexer ("WDM") and a section of active fiber, wherein the WDM forms a multiplexed signal by multiplexing a pump laser signal and an input light signal and wherein the active fiber, using power in the multiplexed signal contributed by the pump laser, generates an output signal from the amplifier that is an amplified version of the input light signal. This system includes an output coupler, an optical bandpass filter and an optical detector, all of which are serially connected.

The output coupler is connected to the output of the optical amplifier and generates a split-off signal that is a lower power version of the amplifier's output signal. Coupled to the output coupler is an optical bandpass filter having a filter bandwidth lying within the amplifier's bandwidth and including a monitoring wavelength. The bandpass filter is configured to block light with power at a signal wavelength that is due to stimulated emission in the active fiber and is coupled to the output coupler so as to provide a bandpass signal that is a filtered version of the split-off signal. The optical detector generates a detector signal representing the power of light input to the optical detector. This detector is coupled to the output of the bandpass filter and therefore generates a detector signal that represents the power in the filter bandwidth of the split-off signal. Because there is a one-to-one correlation between detector signal values and input signal power values, it is possible to estimate
the input signal power from a detector signal value without directly measuring the input signal.

In another preferred embodiment for use with the same type of optical amplifier, an optical bandpass filter with characteristics similar to those described above is positioned in proximity to the active fiber so as to intercept radial emissions from the active fiber. Also included is a wide-area optical detector that generates a detector signal that represents the power of light falling on the optical detector. This optical detector is positioned in proximity to the bandpass filter so that the optical detector receives emissions from the active fiber that have all been filtered by the bandpass filter. As a result, the optical detector generates a detector signal that corresponds to the power in the predetermined bandwidth of the radial emissions from the active fiber. As in the other preferred embodiment, values of the detector signal have a one-to-one correlation with input signal power values.

The present invention is also a method for monitoring input signal power in an optical amplifier wherein the output signal power of the optical amplifier is first measured at a monitoring wavelength that is substantially different from a signal wavelength associated with signals input to the optical amplifier. Then, the input signal power at the signal wavelength is estimated based on a known, one-to-one correlation between the output signal power measured at the monitoring wavelength and the input signal power at the signal wavelength. The estimate of input signal power can be produced by (1) evaluating at a particular measured value of output signal power an analytical function that describes the aforementioned correlation or (2) interpolating, based on a particular measured value of output signal power, the corresponding input signal power from a table of stored input/output signal power pairs characterizing the optical amplifier's performance for a wide range of input signal powers.

The step of measuring output signal power can be performed in two ways. In the first of these methods, an output coupler connected to the output of the
optical amplifier is used to generate a split-off signal that is a lower power version of the output signal. Next, an optical bandpass filter having a filter bandwidth including the monitoring wavelength and excluding the signal wavelength is used to generate a bandpass signal by filtering the split-off signal. Finally, using an optical detector that generates a detector signal that represents the power of light input to the optical detector, a detector signal is generated that represents the power in the filter bandwidth of the split-off signal.

In the second of these methods for measuring output signal power, an optical bandpass filter having a filter bandwidth including the monitoring wavelength and excluding the signal wavelength is used to generate a bandpass emissions signal by filtering radial emissions from the active fiber. Then, using a wide-area optical detector that generates a detector signal that represents the power of light falling on the optical detector, the optical detector being configured in proximity to the bandpass filter so that the optical detector receives radial emissions from the active fiber that have all been filtered by the bandpass filter, a detector signal is generated that represents the power in the filter bandwidth of radial emissions from the active fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and features of the invention will be more readily apparent from the following detailed description and appended claims when taken in conjunction with the drawings, in which:

Figure 1 is a block diagram of a prior art optical amplifier.

Figure 2 is a graph of optical amplifier output signal power versus wavelength for low and high input signal levels.

Figure 3 is a block diagram of a preferred embodiment of the present invention.
Figure 4 is a graph showing amplifier and filter bandwidths in relation to the output signal power plots from Figure 2.

Figure 5 is a plot of an analytical function that defines a one-to-one relationship between input signal power measured at a signal wavelength and output signal power measured at a monitoring wavelength that can be used to estimate input signal power based on a measurement of output signal power.

Figure 6 is a block diagram of the controller and memory of Figure 3 illustrating a technique for estimating input signal power based on pairs of input/output signal powers pre-stored in the memory.

Figure 7 is a block diagram of another preferred embodiment of the present invention.

Figure 8 is a graph of power versus position along the length of an active fiber for the side light and fiber light generated in the active fiber by stimulated emission.

Figure 9 is a flowchart of the method of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring again to Figure 1, in a doped fiber amplifier 100 the signal carrying light (@ 1550 nm) 110 is combined with the light 108 from a pump laser (980 or 1480 nm) 102 into a fiber 106 containing traces (10 to 1000 ppm) of a rare earth ion in its core area. The combining is done using a wavelength selective coupler also known as a wavelength-division multiplexer (WDM) 104. The pump light 108 excites the Erbium ("Er") (or other dopant such as Neodymium ("Nd") or Praseodymium) into a higher energy level that is metastable, i.e., has a long lifetime (10ms in the case of Er, 100 microsec in the case of Nd). The presence of signal light 110 at the proper wavelength
(1520 to 1570 nm in the case of Er, 1310 to 1340 in the case of Nd) causes the ions in the active fiber 106 to decay back to the ground energy level by emitting light coherently with the signal light. This process is known as Light Amplification by Stimulated Emission of Radiation (LASER). The gain of a fiber amplifier 100 is dependent on the difference in ion population between the excited state and ground state. This difference is in turn determined by the pump light intensity, the signal light intensity and the natural relaxation or decay time of the ion.

It is well known that a doped fiber amplifier will have output power between approximately 1510 and 1570 nm. Hereinafter, this range shall be referred to as the “amplifier bandwidth.” It is also well known that doped fiber amplifiers exhibit a phenomenon called amplified spontaneous emission (ASE), wherein pumped ions in the active fiber spontaneously decay, generating light with power within the amplifier bandwidth that is detectable at the amplifier’s output. ASE occurs regardless of the presence of an input signal at the amplifier’s input. However, because active fiber is homogeneously broadened; i.e., all the rare earth ions dispersed in the fiber interact with the signal light, the power distribution of the ASE varies based on whether the active fiber’s input signal is high or low. This is because, when emissions from the active fiber are being stimulated by a high input signal, there are few excited ions to cause spontaneous emissions and, as a result, the power distribution of the ASE is at a low level. In contrast, when the input signal is low and there is no stimulated emission from the active fiber, there is a large population of excited ions to cause spontaneous emissions and the power distribution of the resulting ASE is at a high level.

Referring to Figure 2, there are shown plots of optical amplifier output power versus wavelength that illustrate the relationship between output signal power distribution and input signal level. Plot 210 shows the output signal power distribution for low power input signals (i.e., when there is no input signal, equivalent to a binary "0"). The output power in this case is due entirely to ASE and varies smoothly over the amplifier bandwidth. Plot 220 shows the
output signal power distribution for high input signals (i.e., a binary "1"). The output power in this case is due to (1) stimulated emission at the amplifier’s signal wavelength $\lambda_s$, which produces the power peak at $\lambda_s$, and (2) ASE, which contributes the power lying outside the power peak. Note that the power distribution of the ASE in plot 220 (the high input signal case) is suppressed relative to the power distribution of the ASE in the plot 210.

The present invention makes use of this relationship between ASE and the input signal level to monitor the input signal 110 without outcoupling power from the input signal 110 or otherwise disturbing the input power signal. Consequently, the present invention is able to monitor input power without degrading the signal-to-noise ratio of the output signal 114. Specifically, the present invention monitors power in the output signal due to ASE at a monitoring wavelength $\lambda_m$ that is within the amplifier bandwidth but suitably different from the signal wavelength $\lambda_s$ so that signal power does not contribute to the ASE power measurement. Based on a pre-determined correlation between input signal power at $\lambda_s$ and measured power at $\lambda_m$, the present invention is then able to determine the input signal power. A first preferred embodiment for performing input signal monitoring as per the present invention is shown in Figure 3. A second preferred embodiment, shown in Figure 7, is described later.

Referring to Figure 3, there is shown the first preferred embodiment, which adds to the basic optical amplifier shown in Figure 1 an output coupler 310, a bandpass filter 312, an optical detector 314 and a controller 316, all of which are connected in series. The bandpass filter 312 and optical detector 314 represent common components whose use is well known in fiber optic systems. The filter 312 may be a tunable filter whose passband may be controlled by the microcontroller 316. The controller 316 is coupled to a memory 318, which stores data 320 and/or programs 322 used by the controller 316 to estimate input signal power based on output signal power measurements.
The output coupler 310 receives the original output signal 114 and generates two signals 321 and 323 that have the same power distribution shape as the original output signal 114 (Fig. 2). The repeated output signal 321 contains approximately 99 percent of the power of the first output signal and is the signal that is output from the optical amplifier 100 to other amplifier stages. The monitoring signal 323 contains about 1 percent of the power of the original output signal and is only used to evaluate the output signal power. Of course the two signals 321, 323 can be generated in power ratios other than 99/1 as long as enough power is available for monitoring purposes.

The monitoring signal 323 is input to the bandpass filter 312, which generates a filtered output signal 313 whose power distribution matches portions of the monitoring signal 323 falling within the filter’s bandwidth. As shown in Figure 4, this filter bandwidth is within the amplifier bandwidth, excludes the signal wavelength \( \lambda_a \) and includes the monitoring wavelength \( \lambda_m \). Referring to Figure 3, the filtered output signal is coupled to the optical detector 314, which measures the power in the filtered output signal (i.e., the power at the monitoring wavelength \( \lambda_m \)) and generates a detector signal 315 that represents the measured power in the filtered output signal 313. In the preferred embodiment, the detector 314 samples the filtered output signal 313 only when the SAMPLE signal 319c is asserted by the controller 316. However, the detector 314 could also sample the filtered output at preset intervals. The detector signal 315 is coupled to the input of the controller 316, which determines, based on the value of the detector signal 315, whether the corresponding input signal (i.e., the input signal power at \( \lambda_a \)) was at a low level or at a high level. The controller 316 makes this determination in one of two ways.

In a first method of determining input signal power the controller 316 is programmed to compute values of a preset, monotonic function 322a, an example of which is plotted in Figure 5, that maps output signal power values at \( \lambda_m \) (represented herein as \( P_{\text{output}}(\lambda_m) \)) into corresponding input signal powers at \( \lambda_a \) (represented herein as \( P_{\text{input}}(\lambda_a) \)). Typically, the function 322a is
generated using standard non-linear numerical (i.e., curve-fitting) techniques applied to input and output signal power data collected for a single optical amplifier. Alternatively, the function 322a could be determined analytically based on the known transmission and filtering functions of the WDM 104, active fiber 106, output coupler 310, filter 312 and detector 314.

Assuming that the controller 316 has been programmed to evaluate the function 322a, upon receiving a new value, $P_{315}$, of the detector signal 315, the controller 316 estimates the input signal power corresponding to that value $P_{315}$ by evaluating equation (1) at $P_{\text{Output}}(\lambda_m) = P_{315}$:

$$P_{\text{Input}}(\lambda_s) = f(P_{\text{Output}}(\lambda_m))$$  \hspace{1cm} (1)

For example, $P_{\text{Input}}$ could be equal to: $a + b \times P_{\text{Output}} + c \times P_{\text{Output}}^2 + d \times P_{\text{Output}}^3$.

Note that the analytical function 322a represented by equation (1) is typically generated for an OA at the time of manufacture; however, using techniques disclosed by the inventor of the present application in a related application ("Method and Apparatus for Predicting Semiconductor Laser Failure", Serial Number 08/513,361) the function could be updated during the amplifier's operational life to reflect age-related changes in the amplifier's operational characteristics.

The second method for estimating the input signal power based on the output signal power is illustrated in Figure 6. In this method, at the time of manufacture calibration runs are performed on an optical amplifier 100 wherein output signal power at a preset monitoring wavelength $\lambda_m$, $P_0(\lambda_m)$, is measured for different input signal strengths measured at $\lambda_s$, $P(\lambda_s)$. The results from the calibration runs are then stored in the controller's memory 318 as input/output signal power data 320a. According to this method, upon receiving a new detector signal value $P_{315}$, the controller 316 performs interpolation on the stored input signal power data 320a using the new
measurement \( P_{315} \) and estimates the input signal power (i.e., the power in the input signal at \( \lambda_2 \)) corresponding to the new measurement. As in the first method, the input/output power data 320a could be updated during the amplifier's operational life to reflect age-related changes in the amplifier's operational characteristics.

After determining the input signal power according to either of the above-described methods, the controller 316 compares the estimated input signal power to a preset threshold and issues an alarm 319a when the input signal power is too low. For example, in a typical optical amplifier 100, satisfactory input signal strengths can vary between -18 dB and 0 dB. In such an optical amplifier, the controller 316 would assert the alarm signal 319a whenever the estimated input signal strength is less than -18 dB. Alternatively, the controller 318 can generate a controller output signal 319b that represents the actual estimated input signal power. This signal 319b could be coupled to another controller or a display as a digital or analog signal.

Referring to Figure 7, there is shown another preferred embodiment for monitoring input power without disturbing the input signal, in accordance with the present invention. This embodiment adds to the prior art optical amplifier 100 of Figure 1 an external bandpass filter 412 and a wide-area optical detector 414 and makes use of the controller 316 and controller-related signals 319a-c described in reference to Figure 3. The operations of the filter 412 and detector 414 are known in the art of fiber optic communication systems.

In the embodiment of Figure 7, the external bandpass filter 412 is positioned to filter side, or radial, emissions 407 from the doped fiber 106 (including ASE) and the wide area detector 414 is positioned relative to the filter 412 and the doped fiber 106 so that the detector 414 receives only filtered emissions 413 from the doped fiber. This arrangement is effective as the amount of light traveling axially in the doped fiber 106 is only a small portion of the light generated by stimulated emission in the doped fiber 106. The rest of the light
generated by stimulated emission is emitted radially, outside the doped fiber 106. This radially-emitted light is the light 407 that is filtered by the filter 412 and then received by the wide area detector 414.

Referring to Figure 8, there is shown a plot of power versus position (X) along the length of doped fiber (X = 0 corresponding to the beginning, or left side, of the doped fiber shown in Figure 7) for the "fiber light" 510 and "side light" 512, which terms refer respectively to the light traveling in the fiber and the light 407 emitted outside the fiber. Note that the fiber light 510 has a peak power at the outlet (X = L) of the doped fiber 106 and the side light 512 has a peak power at the inlet (X = 0) of the doped fiber 106. This phenomenon is well-known and is due to the fact that, as the stimulated fiber light moves down the fiber, it is progressively amplified, gradually robbing power from the radial emissions.

As in the embodiment of Figure 3, the output power measurement has a one-to-one correspondence with the input signal power. Consequently, the input signal power can be derived from the output signal power by (1) computing the value of an analytical function that maps the measured output signal power to an input signal power, or (2) referring to calibration tables relating input and output signal power. These methods parallel the methods described in reference to Figures 5 and 6, respectively. However, the function 322a and tabular data 320a used in the embodiment of Figure 7 will differ appropriately from those used in the embodiment of Figure 3 due to the different monitoring techniques employed in the respective embodiments. Having described the preferred embodiments, the method employed by both embodiments will now be set out.

Referring to Figure 9, there is shown a flow chart summarizing the method by which the elements of the present invention determine whether a transmission fault has occurred. The decisional steps, shown as diamond-shaped boxes and data collection are executed in the controller 316 of Figures 3 and 7.
At intervals determined by the controller 316, the detector 314, 414 samples the output signal power at the monitoring wavelength $\lambda_m$ (608). As mentioned above, the sampling intervals could be regular or variable and could be based on the duty cycle of the input signals 110 or on clock-type inputs from another controller. Next, the controller 316 estimates the input signal power based on the power in the output signal (610). If the analytical technique, described in reference to Fig. 5, is being employed to determine the input signal strength (612-YES), the controller 316 evaluates the analytical function 322a relating input signal power to output signal power (614) at a recent detection signal value $P_{315}$ (614). If the table of correlated input and output signal powers 320a are being used to determine the input signal strength as described in reference to Figure 6 (612-NO), the controller 316 estimates the input signal strength by performing interpolation on the data 320a based on the detector signal value $P_{315}$ (616). Upon determining the input signal power, the controller 316 sets an alarm 319a (620) if the input power is below a preset minimum signal level (618-YES). The controller 316 can also, whether (618-YES) or not (618-NO) the input signal power is below threshold, output the current input signal power 319b for use by other controllers or for display (322). The steps of Figure 9 can be repeated indefinitely under the direction of the controller 316.

While the present invention has been described with reference to a few specific embodiments, the description is illustrative of the invention and is not to be construed as limiting the invention. Various modifications may occur to those skilled in the art without departing from the true spirit and scope of the invention as defined by the appended claims.
WHAT IS CLAIMED IS:

1. In an optical amplifier that includes at least one pump laser, a wavelength-division multiplexer ("WDM") and a section of active fiber, wherein said WDM forms a multiplexed signal by multiplexing a pump laser signal and an input light signal and wherein said active fiber, using power in said multiplexed signal contributed by said pump laser, generates an output signal from said amplifier that is amplified version of said input light signal, a system for input signal monitoring comprising:

   an output coupler connected to the output of said optical amplifier, said output coupler generating a split-off signal that is a lower power version of said output signal;

   an optical bandpass filter having a filter bandwidth lying within said amplifier's bandwidth and including a monitoring wavelength, said bandpass filter being configured to block light with power at a signal wavelength that is due to stimulated emission in said active fiber, said bandpass filter being coupled to said output coupler so as to provide a bandpass signal by performing bandpass filtering on said split-off signal; and

   an optical detector that generates a detector signal representing the power of light input to said optical detector, said optical detector being coupled to said bandpass filter so that said optical detector receives said bandpass signal, said optical detector thereby generating a detector signal that represents the power in said filter bandwidth of said split-off signal, values of said detector signal having a one-to-one correlation with input signal power values.

2. The system of claim 1, wherein said power in said filter bandwidth is due to amplified spontaneous emission in said active fiber, a low detector signal value being correlated with a high input signal power and a high detector signal value being correlated with a low input signal power.

3. The system of claim 2, wherein said one-to-one correlation is described by an analytical function relating said detector signal and said input signal.
power, said system further comprising a microcontroller that computes the
value of said input signal power by evaluating said analytical function at a
particular value of said detector signal.

4. The system of claim 3, wherein said microcontroller is configured to
issue an alarm when said input signal power is below an acceptable level.

5. The system of claim 2, wherein said one-to-one correlation is described
by corresponding pairs of input and detector signal powers characterizing said
optical amplifier, said system further comprising:
   a memory in which said corresponding pairs are stored; and
   a microcontroller having access to said memory that computes the
value of said input signal power by interpolating from said corresponding pairs
stored in said memory an input power value corresponding to a measured
value of said detector signal.

6. The system of claim 1, wherein said monitoring wavelength differs
absolutely from said signal wavelength by at least said filter bandwidth.

7. The system of claim 6, wherein said filter bandwidth is substantially
between 1510 nm and 1570 nm when said active fiber is an erbium-doped
fiber amplifier.

8. The system of claim 1, wherein said filter is a tunable filter whose
passband is controllable.

9. In an optical amplifier that includes at least one pump laser, a
wavelength-division multiplexer ("WDM") and a section of active fiber, wherein
said WDM forms a multiplexed signal by multiplexing a pump laser signal and
an input light signal and wherein said active fiber, using power in said
multiplexed signal contributed by said pump laser, generates an output signal
from said amplifier that is an amplified version of said input light signal, a
system for input power monitoring comprising:
an optical bandpass filter having a filter bandwidth lying within said amplifier's bandwidth and including a monitoring wavelength, said bandpass filter being configured to block light with power at a signal wavelength that is due to stimulated emission in said active fiber, said bandpass filter being positioned in proximity to said active fiber so as to intercept radial emissions from said active fiber; and

a wide-area optical detector that generates a detector signal that represents the power of light falling on said optical detector, said optical detector being configured in proximity to said bandpass filter so that said optical detector receives emissions from said active fiber that have all been filtered by said bandpass filter, said optical detector thereby generating a detector signal that corresponds to the power in said predetermined bandwidth of said radial emissions from said active fiber, values of said detector signal having a one-to-one correlation with input signal power values.

10. The system of claim 9, wherein said bandwidth power is due to amplified spontaneous emission in said active fiber, a low bandwidth power measurement being correlated with high input signal power and a high bandwidth power measurement being correlated with said low input power signal.

11. The system of claim 10, wherein said one-to-one correlation is described by an analytical function relating said detector signal and said input signal power, said system further comprising a microcontroller that computes the value of said input signal power by evaluating said analytical function at a particular value of said detector signal.

12. The system of claim 11, wherein said microcontroller is configured to issue an alarm when said input signal power is below an acceptable level.

13. The system of claim 10, wherein said one-to-one correlation is described by corresponding pairs of input and detector signal powers characterizing said optical amplifier, said system further comprising:
a memory in which said corresponding pairs are stored; and
a microcontroller having access to said memory that computes the
value of said input signal power by interpolating from said corresponding pairs
stored in said memory an input power value corresponding to a measured
value of said detector signal.

14. The system of claim 9, wherein said monitoring wavelength differs
absolutely from said signal wavelength by at least said filter bandwidth.

15. The system of claim 9, wherein said filter is a tunable filter whose
passband is controllable.

16. A method for monitoring input signal power in an optical amplifier
comprising the steps of:

measuring output signal power of said optical amplifier at a monitoring
wavelength that is substantially different from a signal wavelength associated
with signals input to said optical amplifier; and

based on a known, one-to-one correlation between said output signal
power measured at said monitoring wavelength and said input signal power at
said signal wavelength, estimating said input signal power at said signal
wavelength.

17. The method of claim 16, wherein said step of measuring output signal
power comprises:

using an output coupler connected to output of said optical amplifier,
generating a split-off signal that is a lower power version of said output signal,
said output coupler reducing power in said output signal by an insignificant
amount;

using an optical bandpass filter having a filter bandwidth including said
monitoring wavelength and excluding said signal wavelength, generating a
bandpass signal by filtering said split-off signal; and

using an optical detector that generates a detector signal that
represents the power of light input to said optical detector, generating a
detector signal that represents the power in said filter bandwidth of said split-off signal.

18. The method of claim 16, wherein said one-to-one correlation is described by an analytical function relating output signal power and input signal power, said step of estimating said input signal power at said signal wavelength comprising:
   computing the value of said input signal power by evaluating said analytical function for a particular value of said bandwidth power.

19. The method of claim 16, wherein said one-to-one correlation is described by table data storing corresponding pairs of input and output signal powers, said step of estimating said input signal power at said signal wavelength comprising:
   locating within said table data a set of said pairs encompassing said measured output signal power value; and
   using interpolation on said set of said pairs based on said measured output signal power value, estimating said input signal power.

20. The method of claim 16, wherein said step of measuring output signal power comprises:
   using an optical bandpass filter having a filter bandwidth including said monitoring wavelength and excluding said signal wavelength, generating a bandpass emissions signal by filtering radial emissions from said active fiber;
   and
   using a wide-area optical detector that generates a detector signal that represents the power of light falling on said optical detector, said optical detector being configured in proximity to said bandpass filter so that said optical detector receives said bandpass emissions signal, generating a detector signal that represents the power in said filter bandwidth of radial emissions from said active fiber.
Fig. 1 Optical Fiber Amplifier
Prior Art
FIG. 4
\[ P_{\text{input}}(\lambda_3) = f(P_{\text{output}}(\lambda_m)) \]

**FIG. 5**
FIG. 6
FIG. 7

FIG. 8
Start

Sample Output Signal at \( \lambda_m \)

Estimate Input Signal Power

Use Analytical Technique?

No

Determine Input Signal Power from Stored Data

Yes

Evaluate Analytical Function at \( P_{355} \)

Input Signal Below Threshold?

No

Output Current Input Power Value

Yes

Assert Alarm

FIG. 9
A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : H01S 3/00
US CL. : 359/341
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/341, 110, 177, 337

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
INSC, COMP, WPI, JAP10 AND APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US, A, 5,442,479 (BULOW ET AL) 15 August 1995, see entire document.</td>
<td>1-20</td>
</tr>
<tr>
<td>Y, P</td>
<td>US, A, 5,506,724 (SHIMUZU ET AL) 09 April 1996, see entire document.</td>
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</tr>
<tr>
<td>Y</td>
<td>US, A, 5,471,334 (MASUDA ET AL) 28 November 1995, see entire document.</td>
<td>1-20</td>
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</table>

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search: 26 MARCH 1997
Date of mailing of the international search report: 09 JUL 1997

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